AD-A192 601 A RESISTIVE-FILM BASED FORCE TRANSDUCER FOR THE STUDY OF EXERCISE(U) ARMY RESEARCH INST OF ENVIRONMENTAL MEDICINE NATICK MA P N FRYKMAN ET AL. JAN 88 1/1

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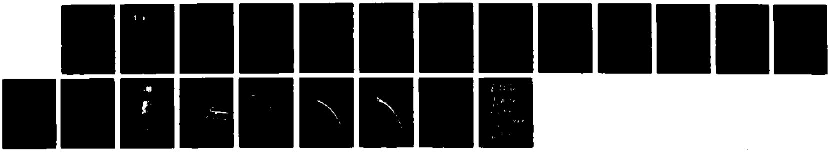

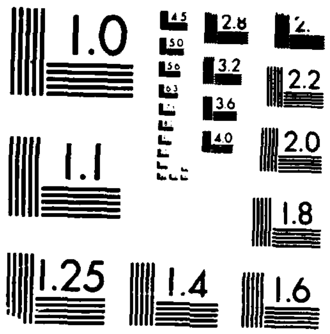

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A new pressure sensitive resistive film was used to construct a pair of force sensing pedals designed to fit a Universal leg press machine. The sensors were calibrated by recording their output voltages on a microcomputer via an A/D converter sampling at 100 Hz as weight was placed on each pedal's top surface. Third order polynomial equations were fit to the data and resulted in correlation coefficients between actual and predicted force of .9965 for the right pedal and .9918 for the left. Within day reliability coefficients were .9997 and .9994 for the right and left pedals respectively, while across day reliability coefficients were .9989 and .9877. The upper limit of accurate force transduction is over 5000 N per pedal. The pedal transducer is reliable, valid, inexpensive, and relatively easy to work with. The resistive film requires considerably less engineering than do strain gages in the construction of transducers to measure forces applied to a flat surface. Keywords: pressure measurement; pressure switches; exercise (physiology)

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A resistive-film based force transducer for the study of exercise

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A resistive-film based force transducer

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Abstract

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STRENGTH, WEIGHT LIFTING MACHINE, POWER, WORK

Introduction

In the study of human performance, it is often desirable to measure forces exerted against a surface. Strain gages (1) provide very accurate transduction of forces, but they can be difficult to incorporate into a force sensor. Force plates are surface force transducers that are highly accurate but expensive and are mainly used to detect ground reaction forces.

The use of force transducers with resistive exercise devices makes it possible to measure force application throughout an exercise movement. The addition of a position transducer allows calculation of work and power. The instrumented machine can then be used as a device to determine force, work and power capabilities.

Some commercial resistive training/testing devices provide force and power information. However, they are usually expensive and are not widely available for sport training or exercise labs. It is highly desirable to be able to inexpensively instrument commonly available training devices such as adjustable weight stack machines.

To meet the force transduction needs for a study examining the leg press exercise, a set of detachable force sensing pedals was constructed to fit a standard Universal (Cedar Rapids, Iowa) leg press machine.

Methodology

Figure 1 shows the force transducers made by modifying a set of Universal leg press pedals. The force sensing element in the pedals is a proprietary electrically resistive film from Interlink Electronics Corp.(Santa Barbara, CA) that transduces external pressure into voltage. It is comprised of two parts: 1) a grid of electrically conductive strips, and 2) a sheet of the electrically resistive material. The resistive material is a proprietary ink that is screen printed onto a polyester substrate film. The film's electrical resistance decreases as the grid is pushed into closer contact with the surface of this ink. The force sensing resistive film has a pressure limit of approximately 758 kilopascals (110 psi). Beyond this pressure the resistive response becomes essentially flat, with almost no change in electrical resistance with increasing pressure. The film is maximally rated at one milliamp and one and a half volts dc.

The foot pedals were altered by filling the concave areas (where the feet are placed) with aluminum-epoxy putty. The filled areas were then machined flat and parallel to each other to provide as large a surface for the force sensors as possible. Given the pressure limit of 758 kPa, the pressure contact zone of .0148 m^2 allowed a maximum force of 11,218 N per pedal. This high force limit was more than double the highest anticipated leg press forces. A pilot test indicated the response of the material flattened at a pressure lower than the 758 kPa indicated by the manufacturer. Building such a large force handling capability into the sensor assured that the highest output voltage would be within the usable portion of the response curve.

The two elements of the force sensing resistive film were cut to fit the top surface of the right and left pedals. An aluminum top plate was made to fit over the area covered by the force sensing resistive film on each of the pedals. The undersides of these top plates each have a raised "plunger" area to transmit pressure to the film (Fig.1). These plates were located over the base plates by means of three screws. The screws however, did not restrict the transmission of force from the top surface to the FSR.

The force sensing resistors required an excitation signal that did not exceed the one and a half volts dc and one milliamp ratings of the film. An unregulated power supply, such as a battery with appropriate current-limiting circuitry could have been used. However, this would have necessitated monitoring the excitation voltage and periodically altering the device's calibration factors to account for changes in the excitation signal. An off-the-shelf constant voltage power supply that did not exceed the current and voltage ratings of the film could also have been used.

To power the pedals an adjustable voltage, current-limited excitation source was constructed that incorporated an output buffer to strengthen the signal from the force sensing resistors. To help prevent possible distortion of the signal the buffer maintained the transducer output impedance much lower than the input impedance of the recording device (an A/D board). The excitation source/buffer also provided zero and span control and gave the flexibility to use it with other low power transducers. A schematic of this circuit appears in Fig 2.

Calibration

The pedals were cradled in sandbags to stabilize them with their upper surfaces horizontal so that the force of the weights stacked on them acted perpendicularly to the pedal surfaces. Weights totaling 1669 N were stacked on the top plate of each pedal in 49 N increments. Output voltages from the pedals were sampled and converted to numbers at a rate of 100 Hz by an analog to digital converter from Infotek Systems

(Anaheim, CA). The data were stored in a Hewlett-Packard 310 computer (Burlington, MA).

Because the electrical response of the force sensing resistive film was not linear it was necessary to mathematically fit curves to the calibration data. Using the polynomial fitting subroutine RCURV from IMSL Inc. (Houston,TX), it was determined that the following equation provided a good fit to the transducer output versus force data.

$$F = aV^3 + bV^2 + cV + d$$

Where: F = force exerted on the pedal (N).

V = integers produced by the A/D converter proportional to the transducer output voltage.

a,b,c,d = constants produced by the fitting subroutine.

Table 1. shows the constants for the left and right pedals.

The differences between these two equations is due to small differences between the size and electrical properties of the two sheets of resistive material used in the different pedals. Interlink Electronics states that resistance varies up to 20% between different sheets of the film. Thus, any transducer made of the film would have to be calibrated individually. Figure 3 shows calibration data for the right and left pedals. The correlation coefficients between the actual and predicted forces were .9965 for the right pedal and .9918 for the left pedal. Figure 4 shows transducer output from a set of leg press exercise.

To establish the reliability of the force sensing pedals, test-retest reliability analysis was executed on calibration data collected on the same day and on two different days. Across-days test sessions were two days apart and at the same time of day. A trial consisted of stacking calibration weights on a pedal and taking an output voltage reading for each weight increment. The right and left pedals were calibrated separately. Five sets of calibration trials were completed within each test session with a time between trials of one to five minutes. The coefficients in table 2 show that the transducer was highly reliable both within and across days.

Discussion

The pedals provide high resolution force production data. By adding a sensor to determine the position of the weight stack at the time of each force measurement, work and power can be monitored as well.

The relative ease of data collection and the low cost of this transducer makes it an attractive addition to biomechanics and strength physiology laboratories. The portability of the pedals from machine to machine facilitate their use in field studies. Similar force sensors could easily be constructed for other types of resistance exercise devices. The force sensing resistor film can be incorporated into a wide variety of laboratory testing instruments that could be used in conjunction with physiological and biochemical data collection techniques.

Acknowledgments

We would like to thank Sgt. William Sawyer for his technical assistance in producing the drawings for this paper.

Disclaimer

The views opinions, and/or findings contained in this report are those of the authors and should not be construed as as official Department of the Army position, policy, or decision.

References

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Table 1. Coefficients for right and left pedal equations.

Constant	Left pedal	Right pedal
a	$.708105 \times 10^{-6}$	$.358478 \times 10^{-6}$
b	$-.314361 \times 10^{-3}$	$-.332397 \times 10^{-3}$
c	$.760128 \times 10^{0}$	$.596041 \times 10^{0}$
d	$.200808 \times 10^{2}$	$-.115675 \times 10^{2}$

Table 2. Test-retest reliability analysis on force sensing pedals

Test	Left pedal	Right pedal
	(Reliability coefficients)	
Test-retest(within day)	.9994	.9997
Test-retest(across days)	.9877	.9989

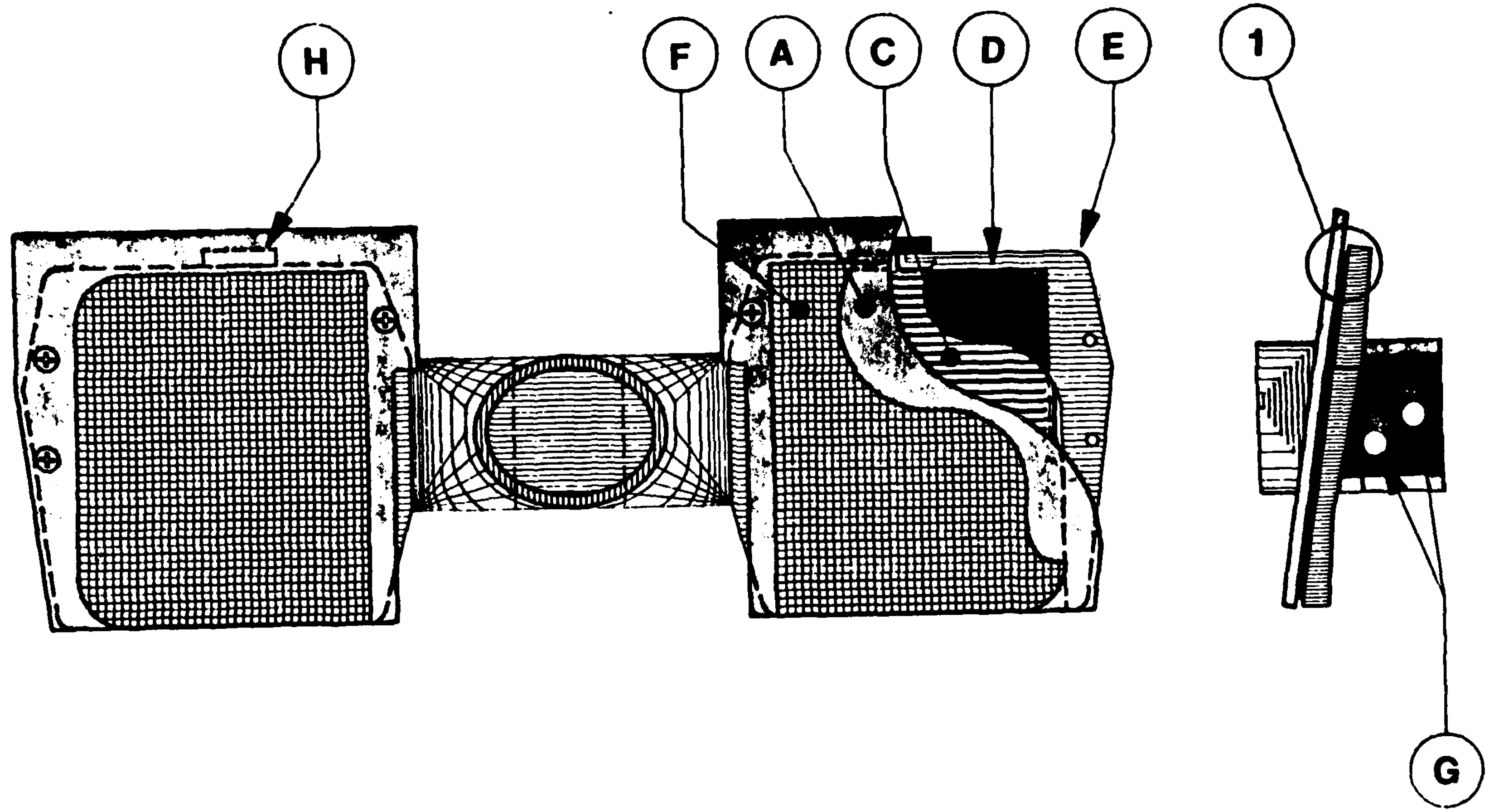
Captions for figures

Fig. 1 Top and end views of force sensing pedals showing: a) Top plate b) Plunger area of top plate c) Interdigitated silver electrode array d) Resistive ink layer e) Base plate of pedal f) Anti-slip coating g) Holes for mounting transducer pedals to leg press machine h) Electrical connector to FSR.

Fig. 2 Schematic of power supply and force sensing resistors(FSR) (A) Adjustable reference voltage source, (B) Excitation/buffer channel (one of two), (C) High frequency filter and current limiter.

Fig. 3 Force vs digitized transducer output voltage with the third degree polynomial best fit calibration curves for (A) right and (B) left pedals.

Fig. 4 Graphs of forces exerted on right and left pedals during a maximal (1RM) leg press.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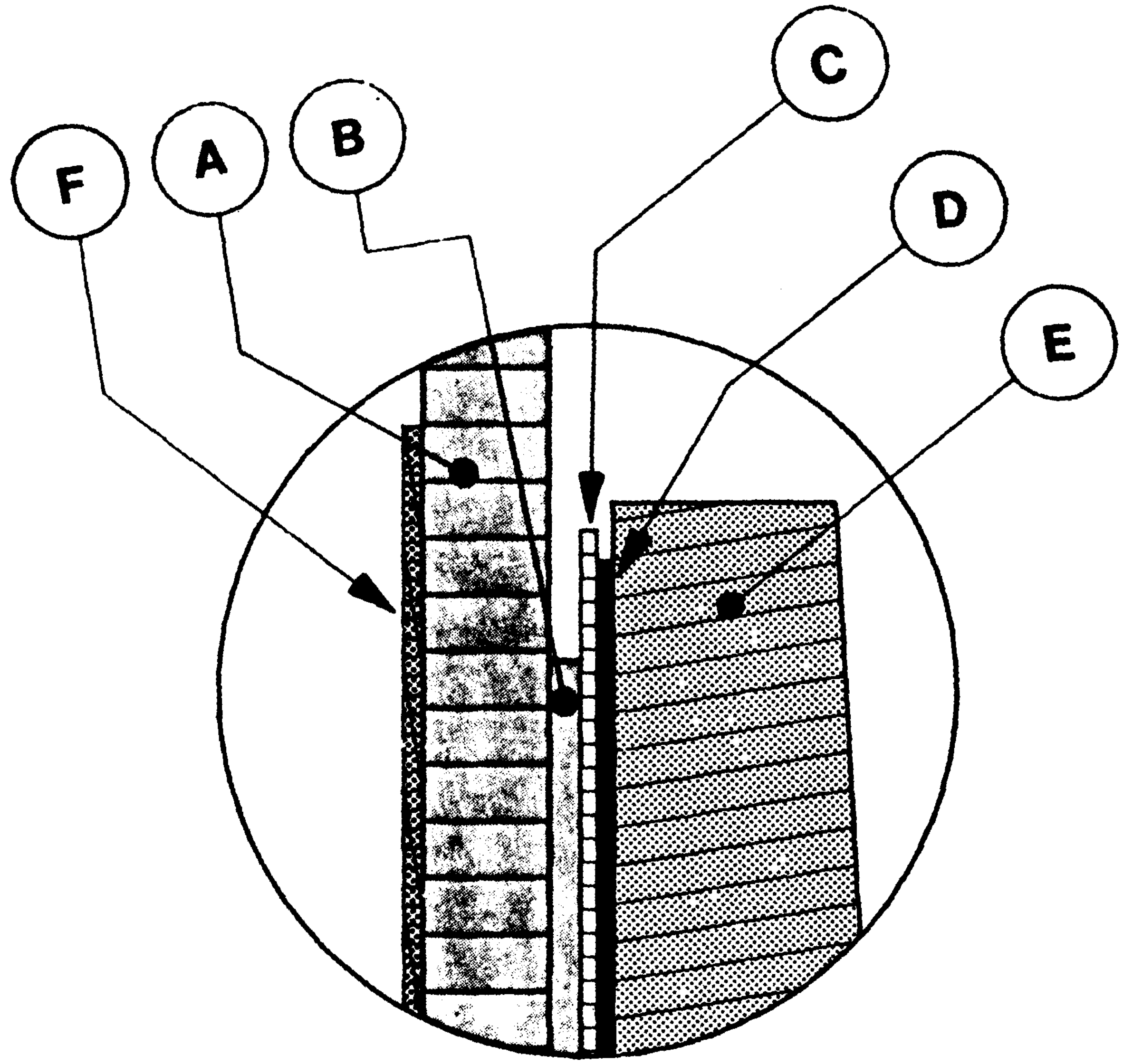
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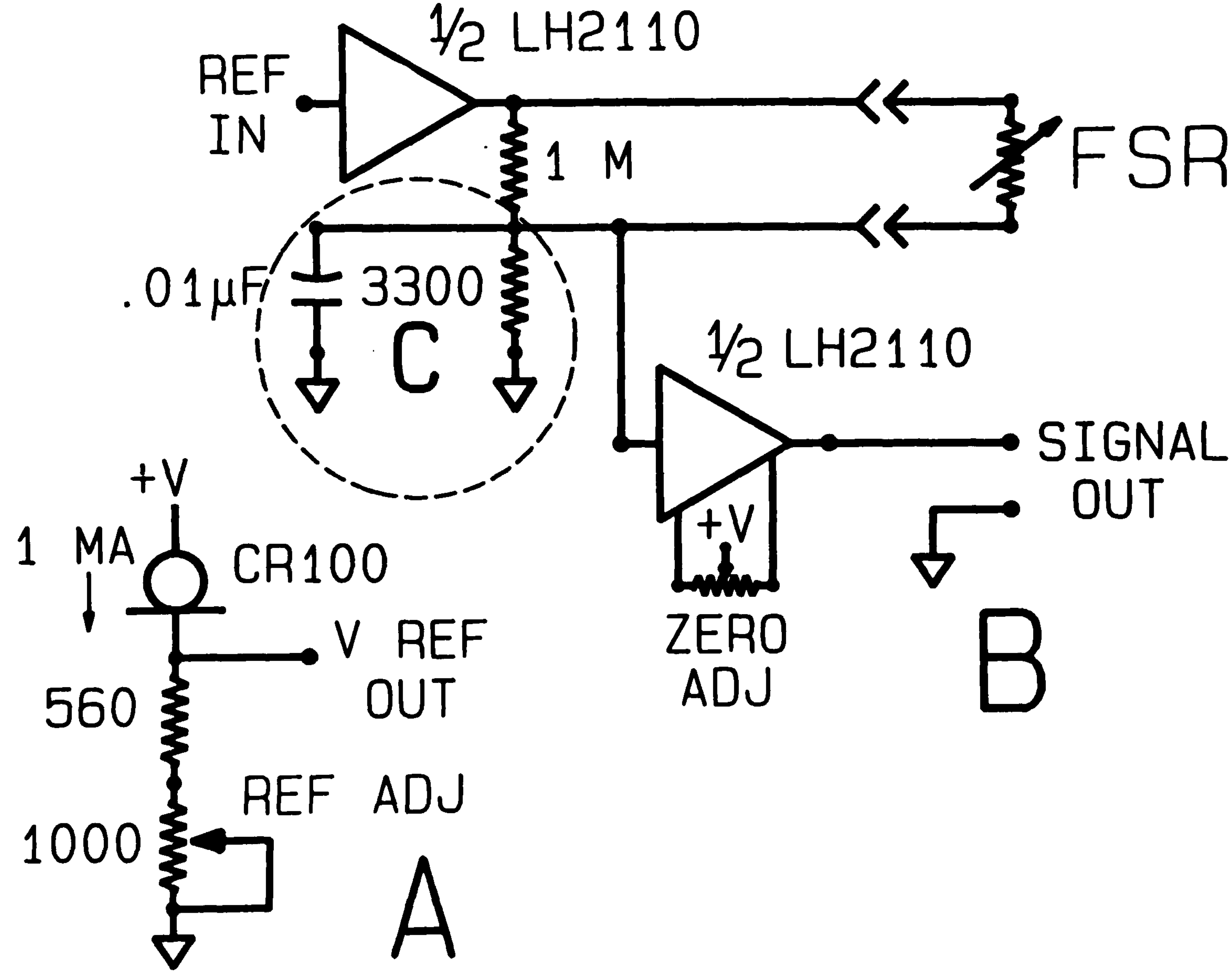

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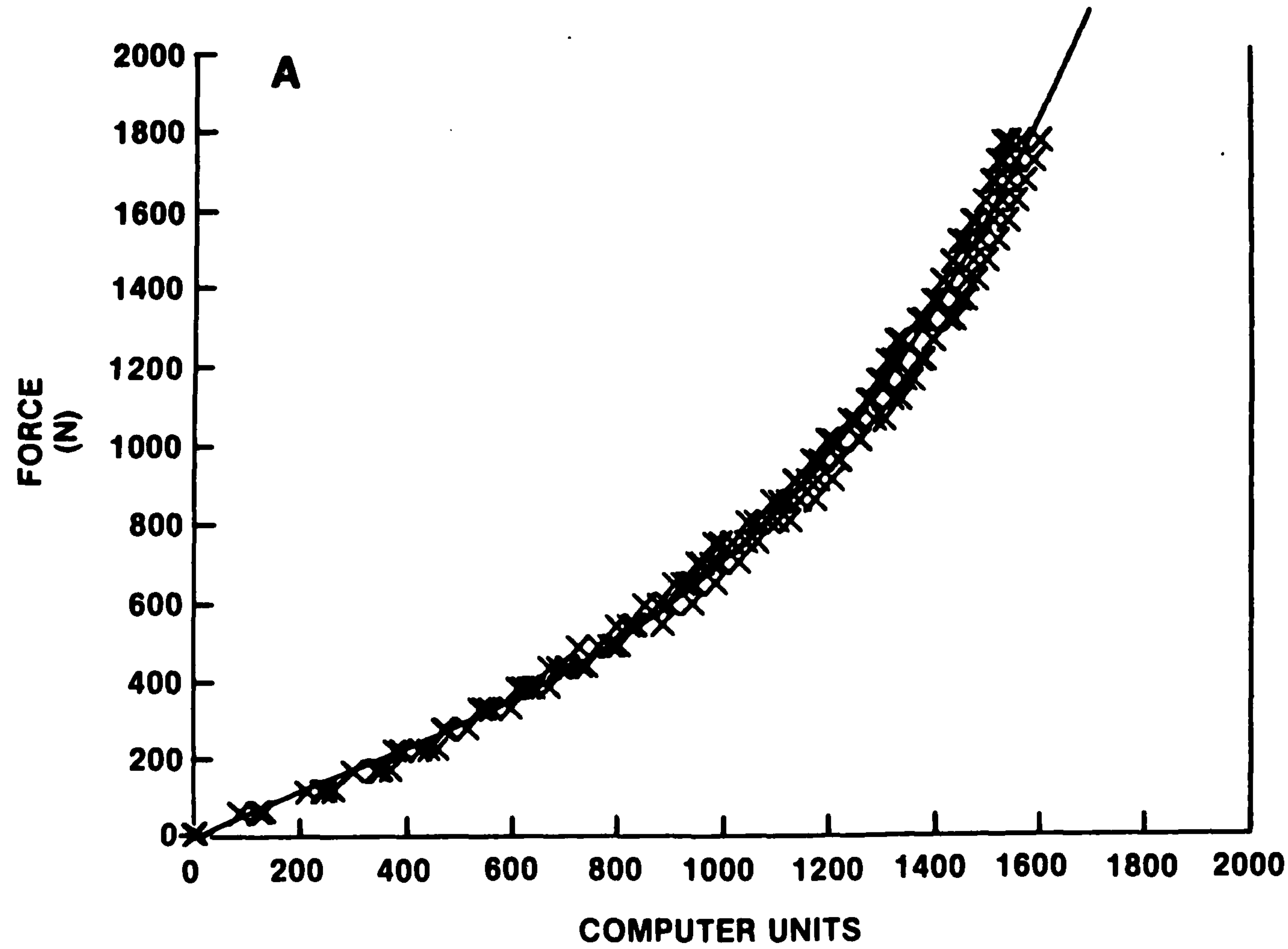
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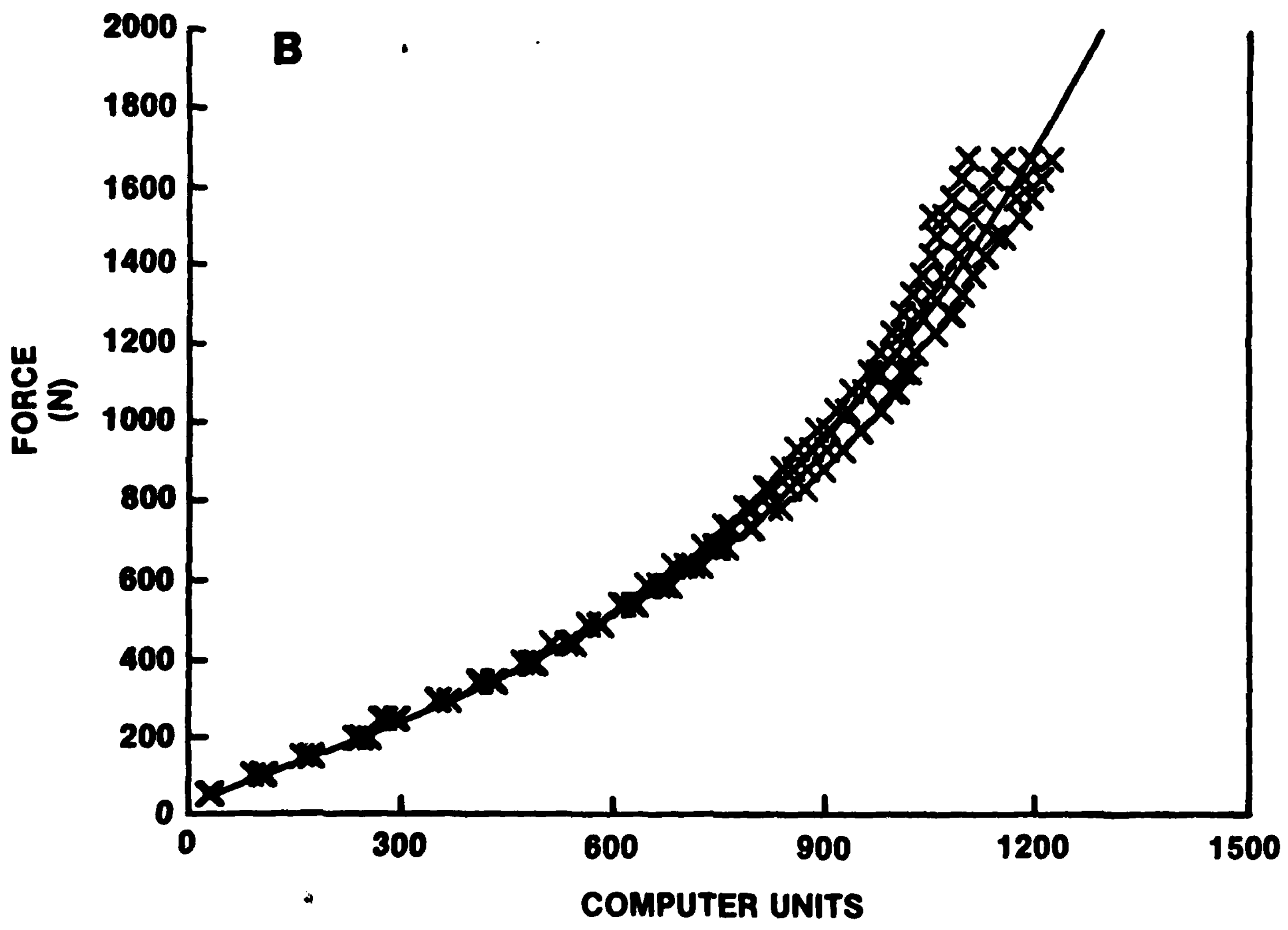
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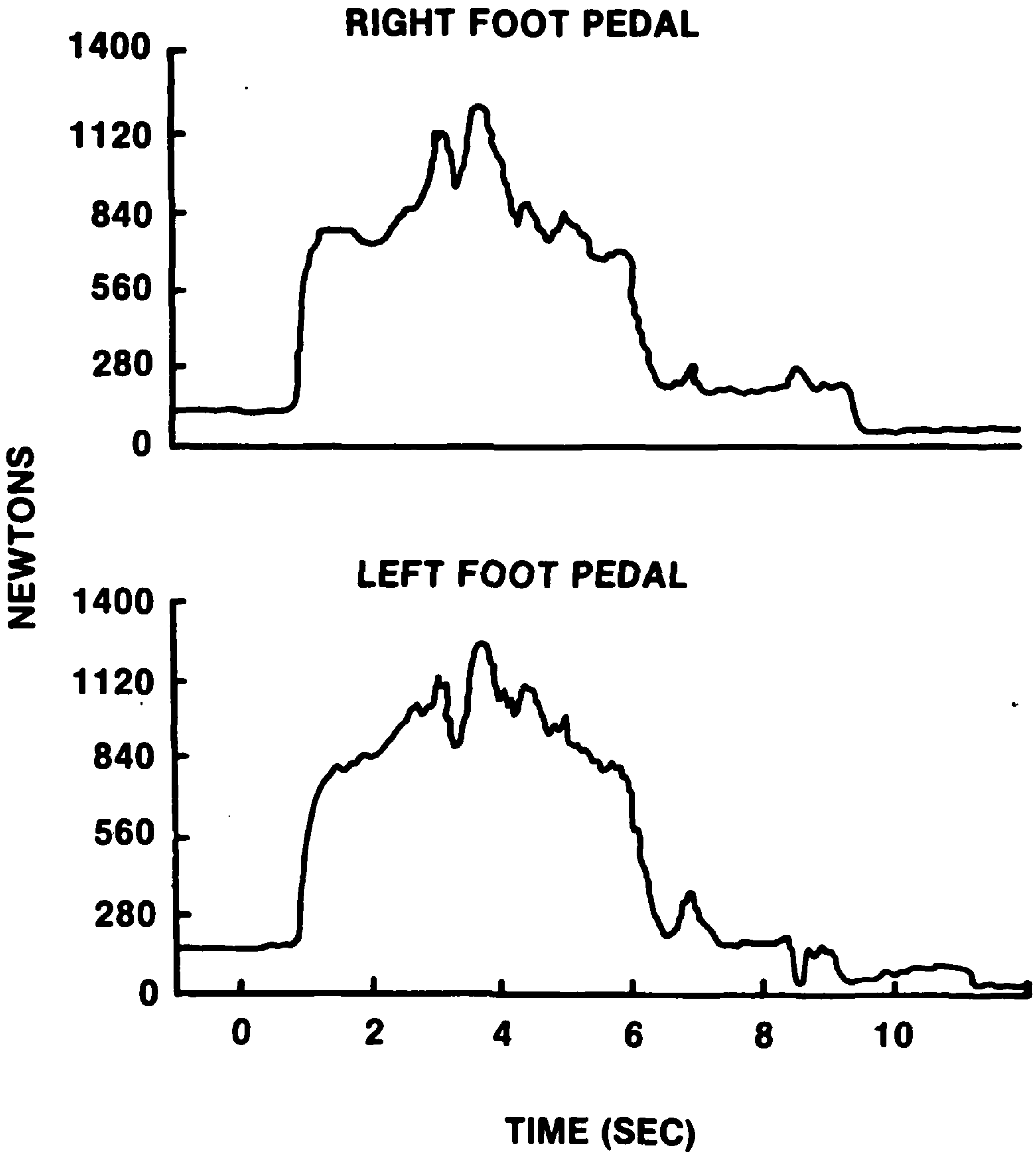
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